

PHENOMENOLOGICAL INVESTIGATIONS
IN HADRON PHYSICS
WITH EMPHASIS ON QUARK STRUCTURE

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This thesis is based on the following publications:

- I. High Energy π N Backward-Scattering Models and Continuous Moment Sum Rules.
Il Nuovo Cimento 26A (1975) 1.
(Together with L.Sollin)
- II. Evidence for a Fixed $J=0$ Pole in Pion Compton Scattering.
Lettere al Nuovo Cimento 13 (1976) 460.
- III. Rescattering effects in the decay of the A_1 .
Nuclear Physics B116 (1976) 301.
(Together with G.Gustafson)
- IV. On the Diffractive Production of Charmed Baryons.
Physics Letters 67B (1977) 81.
(Together with G.Gustafson)
- V. A Comparison of the Quark Parton Model with Data on Electroproduction of Pions.
Lund Preprint LU-TP 77-8. (To be published)
(Together with G.Gustafson)
- VI. A Quark Parton Model for Hadron Fragmentation Distributions.
Lund preprint LU-TP 77-7. (To be published)
(Together with B.Andersson and G.Gustafson)
- VII. The Relationship between the Meson, Baryon, Photon and Quark Fragmentation Distributions.
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INTRODUCTION

Particle physics is very much characterized by the creation and annihilation of matter. It is therefore tempting to believe that quantum field theory is a suitable framework in which the fundamental laws of elementary particles can be studied. In the case of the electromagnetic force such a program has been very successful. This is much due to the knowledge of the classical limit and to the smallness of the electromagnetic coupling constant, which justifies a perturbative solution of the theory. In the case of strong interactions such advantages do not exist and attempts to set up a realistic quantum field theory have not been successful apart from some recent developments, which will be mentioned below. Instead much effort during the last decades has been devoted to a phenomenological understanding of existing experimental data with varying degree of theoretical sophistication. One such approach has been to use analyticity properties of the scattering amplitudes, which are derived from fundamental properties like causality and unitarity, in order to get selfconsistency of the data and further insight to the dynamics. Also models have been constructed as generalizations of results known in non-relativistic potential theory like the Regge-pole model and modifications of it. Paper I, II and III contain different phenomenological approaches in this spirit.

Parallel to these developments great progress was made in grouping the vast amount of experimentally found particles into multiplets of higher symmetries in particular those associated with the group $SU(3)$. Due to this success much experimental effort has been devoted to find particles corresponding to the basic representation of $SU(3)$, the quarks, which have fractional charges. All such searches have however given negative result. In the late 60's measurements on the

reaction $e^-p \rightarrow e^-X$ (X stands for an unidentified hadron system) were carried out at large energies and momentum transfers. This so called deep inelastic scattering process is analogous to Frank Herz experiment in atomic physics. The fact that the cross section turned out to depend only on dimensionless combinations of kinematical variables and not on any parameters with the dimensions of mass, which set the scale, is easily interpreted in terms of a model, where the proton consists of pointlike constituents, partons. Moreover studies of the angular distributions suggest a spin $1/2$ assignment for the partons and similar experiments with weak interaction probes (e.g. $\nu p \rightarrow \mu^- X$) indicate that the partons can be identified with the basic entities of $SU(3)$, the quarks u, d and s as far as quantum number are concerned. The phenomenological picture that emerges for these processes is that a quark parton is kicked out of the target and it subsequently fragments into final state hadrons. The momentum distribution of these hadrons should accordingly be jetlike, which seems to be the case experimentally. This quark-parton model also explains the energy behaviour and magnitude of the cross section for $e^+e^- \rightarrow$ hadrons, in which the two step picture $e^+e^- \rightarrow$ quark-antiquark $\rightarrow$ hadrons is assumed. Also here the distribution of the final state hadrons strongly resembles a jet picture, now with two jets characteristic for an intermediate pair of spin $1/2$ quark and antiquark. Still there remains the question why the quarks never emerge with their characteristic non integer charge in the reactions above, where they seem to play such an important dynamical role. Whatever this confinement mechanism is, the phenomenological quark parton picture is consistent in the sense that the process of a quark q fragmenting into a final state hadron h is experimentally described by the same function D_q^h for the different reactions in question. In paper V data on $e^-p \rightarrow e^- \pi^+ X$ are analyzed by means of the quark parton model.

The success of the quark parton model has revived the interest in quantum field theory. There exists one candidate theory for strong interactions, Quantum Chromodynamics (QCD), in which the basic quarks are coupled to neutral vector particles. These so called gluons are analogous to the photons in quantum electrodynamics. The theory reproduces the quark parton model results in the deep inelastic limit and has furthermore long range properties in which quark confinement is possible. This latter feature has however not yet been proven.

Recently narrow resonances were, discovered in $e^+e^- \rightarrow$ hadrons and hadron-hadron collisions. These are interpreted as bound states of heavy charmed quarks. Further searches for charmed hadrons are suggested in paper IV. It should be emphasized that these new charmed particles should provide us with an important experimental handle on the dynamics of QCD. Their features may namely more reflect the properties of the underlying field theory than other hadrons due to the large charmed quark masses and their subsequent nonrelativistic bound state motion.

The great success of the quark-parton model in describing the dynamics in lepton-induced reactions has stimulated efforts in developing an equally fundamental explanation of the regularities observed in pure hadronic interactions. One of the main features in hadron-hadron collisions is that the secondaries are produced mostly along the collision axis with an exponential fall off in the transverse momentum distribution. At high transverse momentum, however, more particles are produced than expected from this distribution. These events can be interpreted as originating from collisions of partons belonging to the impinging hadrons. The general features of such an idea are realized in experiments, but the question of the detailed structure of the parton-parton interaction is not yet settled.

Guided by the gross similarities between the distributions of secondaries in the forward region in hadron-hadron collisions and the jets observed in $e^-p \rightarrow e^-X$ and $e^+e^- \rightarrow \text{hadrons}$ an extension of the quark parton model is suggested in paper VI and VII. It is assumed that one of the quarks or antiquarks of the incoming projectile gets stuck in the target whereas the spectator quark(s) continue and fragment into hadrons according to the functions D_q^h or their diquark generalizations. Very good agreement with the presently available data is obtained and many predictions of the theory will be tested in the near future. This universal quark parton picture for multiparticle production phenomena is very appealing with its few parameters and large domain of validity.

SUMMARY OF PAPERS

Continuous Moments Sum Rules (CMSR) are derived from analyticity properties of the scattering amplitudes. Such sum rules can be used to determine parameters of models for the high energy region like the Regge pole model by means of low energy data. In paper I CMSR are used to discriminate between different high energy models in πp backward scattering. It should be remarked that the kinematic domain, in which the CMSR are valid in backward scattering is very limited. Another difficulty is the lack of sufficient experimental knowledge of the t-channel ($\pi\pi \rightarrow N\bar{N}$).

The unitarity condition constrain the position of poles in the complex angular momentum plane to be moving with energy in pure hadronic processes. Due to the smallness of the electromagnetic coupling this is not the case in photoinduced reactions. In paper II a fixed $J=0$ pole is assumed for the γp -system. By saturating a dispersion sum rule by known resonances the residue of the $J=0$

pole is estimated to be of the order of the Thomson limit $-\alpha/m_\pi$. This value is consistent with the vector dominance picture of the photon.

The quark model predicts the existence of a $J^{PC} = 1^{++}$ meson. The enhancement observed in the diffractively produced 3π -system at 1100 MeV in πp -reactions has been considered as a candidate for this so called A_1 meson. The partial wave analyses of the 3π -system around this enhancement do however not show a phase variation characteristic for a pure resonance. These partial wave analyses are based on the isobar model, where the production amplitude for the three particle state is dominated by a quasi two body state. This approximation violates unitarity and in paper III rescattering corrections are taken into account in order to correct the isobar model for unitarity. Fairly small effects are obtained, which justifies the use of a nonunitarized isobar model in the partial wave analysis and explains why these analyses give good fits to the data. This result is also applicable in a non diffractive production processes.

Since the discovery of the charmonium states (ψ and ψ') and subsequently the charmed mesons in e^+e^- -reactions, much effort has been devoted to find charmed mesons and baryons in hadronic reactions. It is difficult to make firm theoretical predictions on cross sections etc., but estimates by using for example analogies with strange particle production might be useful.

In paper IV arguments are presented in favour of producing charmed baryons in diffractive scattering. The main idea is based on the observation that in the strange case it is easier to produce a Λ diffractively than in direct production and the assumption that a diffractively produced object might decay by polarizing a strange or charmed quark out of the vacuum. Using quark mass ratios and data on

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Λ production we estimate the cross-section for production of charmed baryons at high energies to be 10-100 μb.

The probability to find a u- or a d-quark in the proton with a fraction x of the proton momentum is, in the quark parton model, given by $u(x)$ and $d(x)$ respectively. These are determined from data on the reactions $e^-p \rightarrow e^-X$ and $e^-n \rightarrow e^-X$. This latter reaction is not directly measurable but has to be extracted from the corresponding deuterium process, which is not an unambiguous procedure.

In paper V a simple way of determining $d(x)/u(x)$ from data on electroproduction of pions ($e^-p \rightarrow e^-\pi^\pm X$) without using deuterium data is therefore suggested. Moreover a recent pion electroproduction experiment is analyzed in terms of the quark-parton model. Deviations from this model is found, which cannot be explained by scalebreaking effects such as the effects of target mass, quark mass or an interaction mass scale. Instead the experimental data seems to indicate that the transverse momentum distributions of the u- and d-quark within the proton are different and may even be x dependent.

The observed spectra of produced secondaries in hadron-hadron collisions and in deep inelastic processes are very similar. It is therefore tempting to assume that the quark-parton model also plays an important role in pure hadronic processes with small transverse momentum. Such an approach is also motivated by the success of the additive quark model, in which various hadronic cross sections are related to each other by quark-quark subcross-section decompositions.

In paper VI the attention is focused on meson fragmentation in a model where one of the valence quarks (or antiquarks) participates in a central collision, whereas the remainder continues with almost all the incoming momentum. This leading quark develops a string-like field, which subsequently materializes into hadrons. In this way the quark fragmentation function $D_q^h(z)$ as determined in lepton-induced reactions are able to describe various single particle spectra without new parameters and additional assumptions. Here z denotes the fraction of the parent quark momentum carried by the produced hadron.

In paper VII these ideas are carried further to the case of photon and baryon fragmentation. When treating the photon as a mixture of the ρ - and ω -mesons according to the Vector Dominance Model again good agreement with data is obtained. In the case of baryon fragmentation it is assumed that a valence diquark system is responsible for the fragmentation spectra. Diquark fragmentation functions $H_{qq}^h(z)$ analogous to $D_q^h(z)$ are introduced in order to explore the phenomenological consequences. In leptonproduction experiments these are weighted by quark distributions (e.g. $u(x)$ and $d(x)$) whereas in the pure hadronic case simple statistical factors determine the weights. Within this picture the baryon fragmentation distributions of the different processes are consistent with each other, but more high statistics leptonproduction experiments are needed to definitely verify this branch of the theory. In particular there are very strong predictions for π^+/π^- -ratios in the baryon fragmentation regions of ν and $\bar{\nu}$ induced reactions.

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